Surface Studies of Hydrogen Isotopes on Tungsten

R. Bastasz, M. D. Coventry*, J. A. Whaley
Sandia National Laboratories, Livermore, CA
*University of Illinois, Champaign, IL

Outline

introduction:	Background and motivation H isotope recycling from W
results:	Recoil energy measurements Desorption cross section measurements
analysis:	Interpreting the recoil energy spectrum.
conclusions:	Implications for H isotope recycling from W.

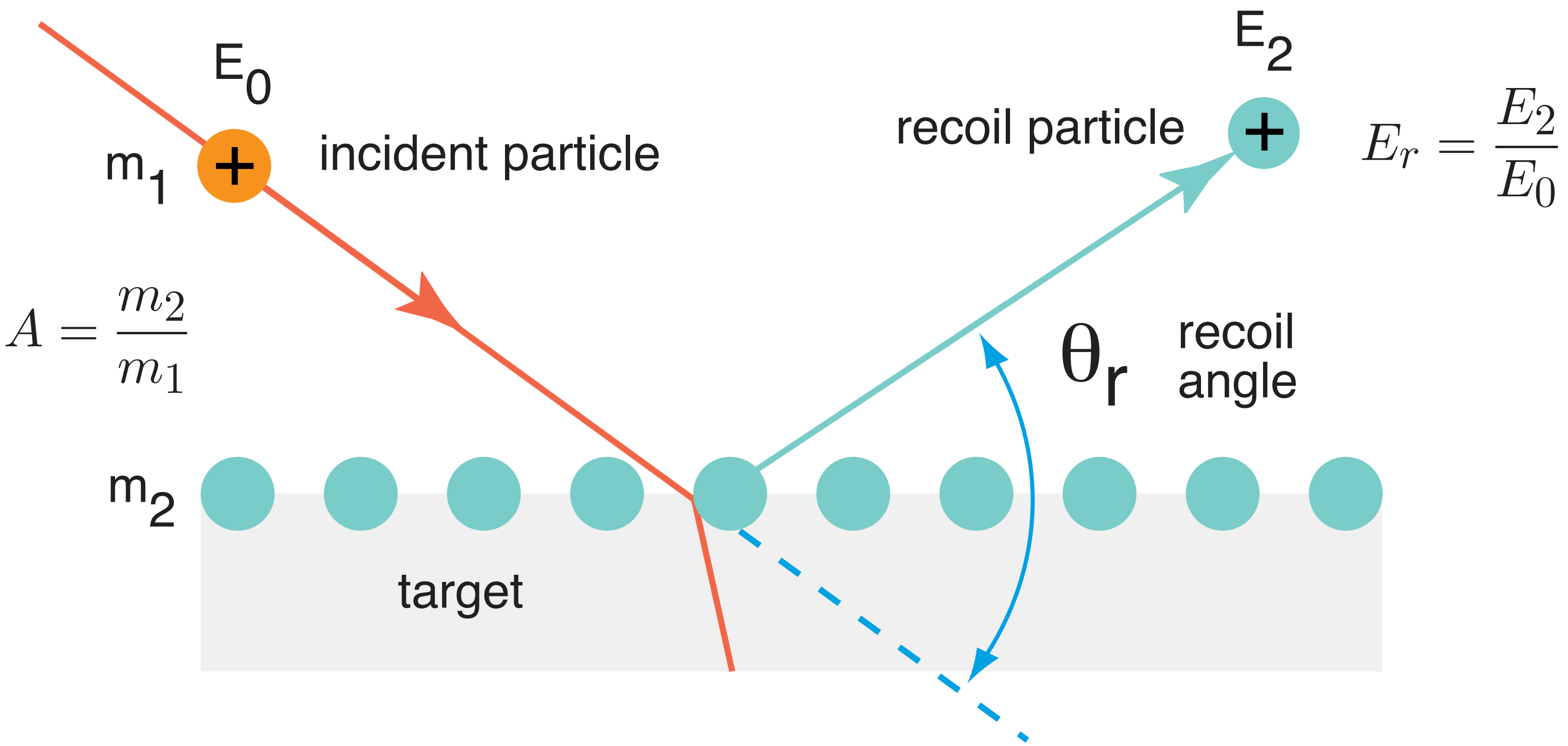
Materials & Engineering Sciences Center
Atoms to Continuum

Background

- Tungsten readily adsorbs molecular hydrogen.
- Tungsten is a high recycling material.
- The energetic portion of the recycle flux consists of two components:
  1) reflection of incident hydrogen isotopes
  2) recoil of adsorbed hydrogen isotopes.
- The reflection component has been well studied with both modeling and experiment.
- The recoil component has received less attention and is the subject of this study.

We measured the energy of H and D recoil ions ejected from clean W surfaces.

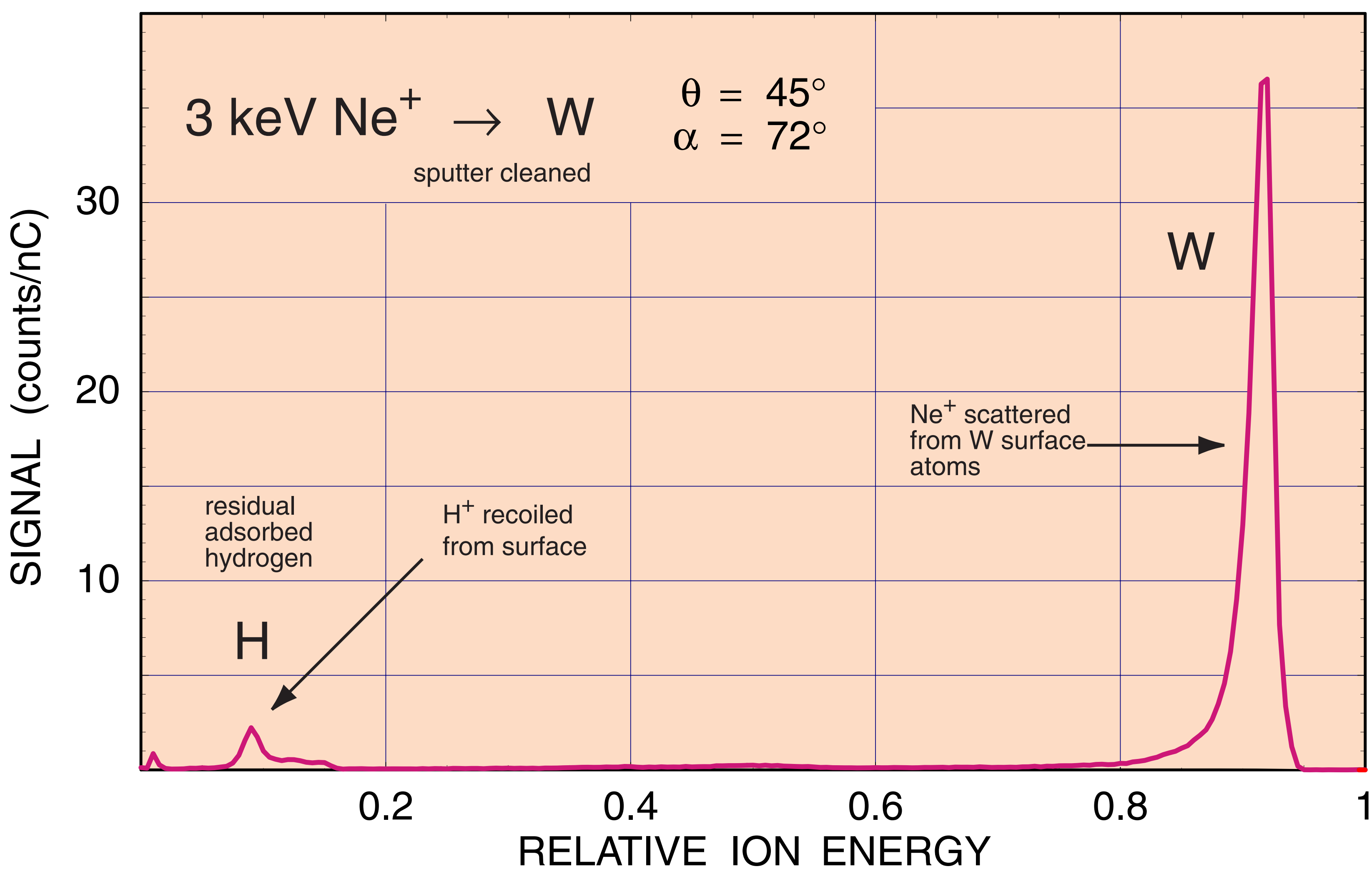
DRS: direct recoil spectroscopy



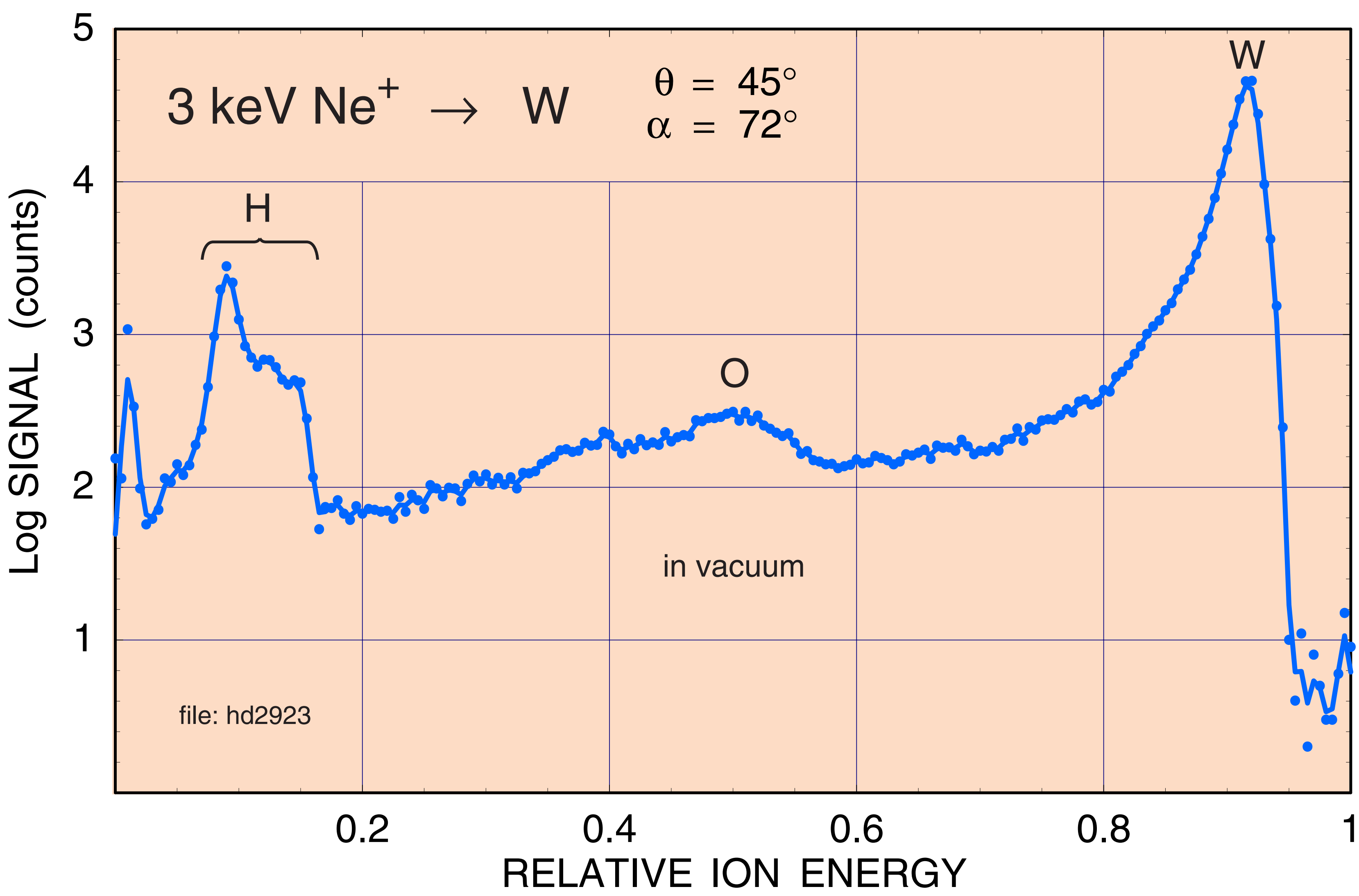
$$2\cos\theta_r = (1 + A)\sqrt{E_r/A}$$

(for elastic recoil)

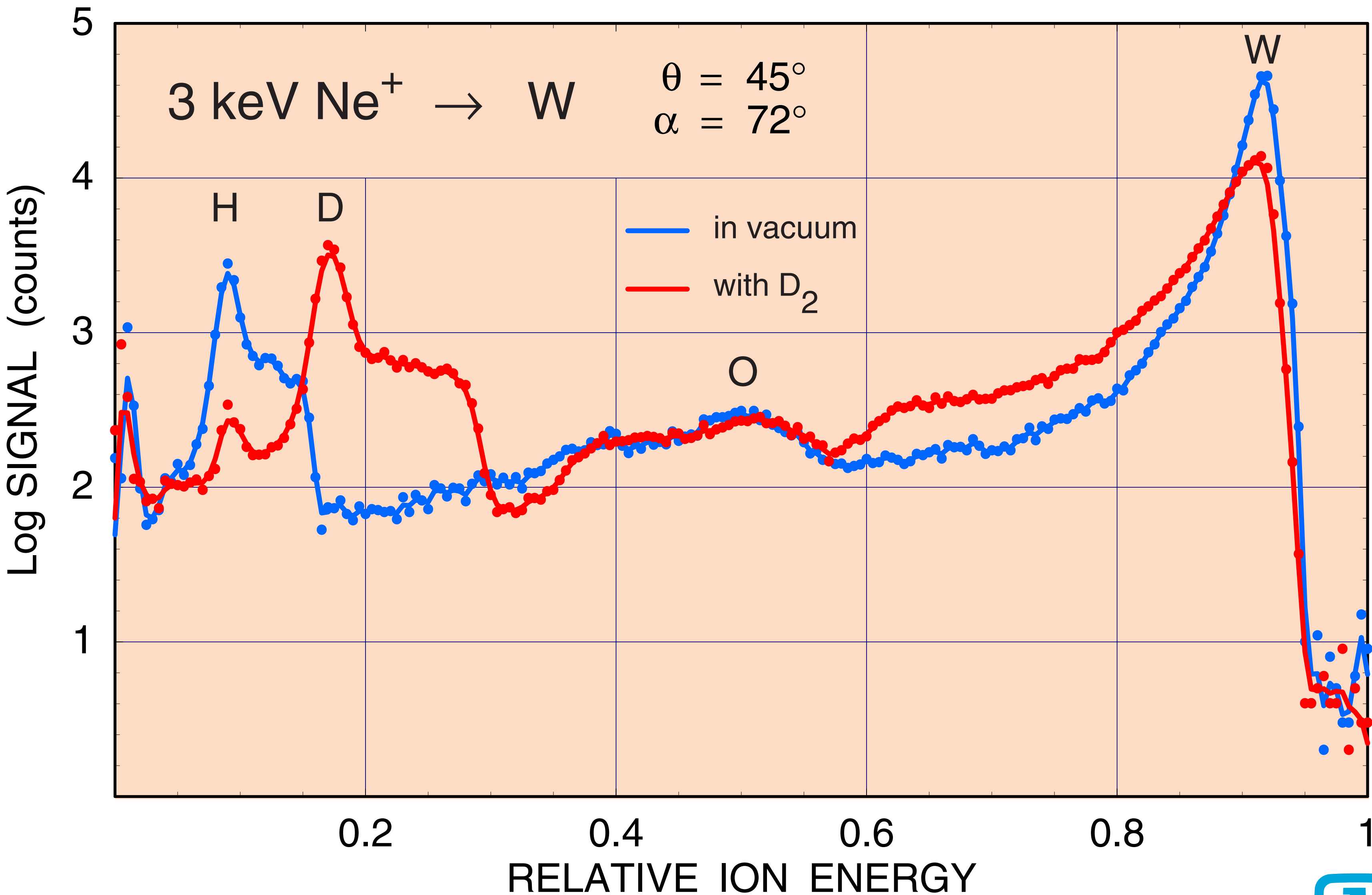
Ion energy spectra identify surface atoms.



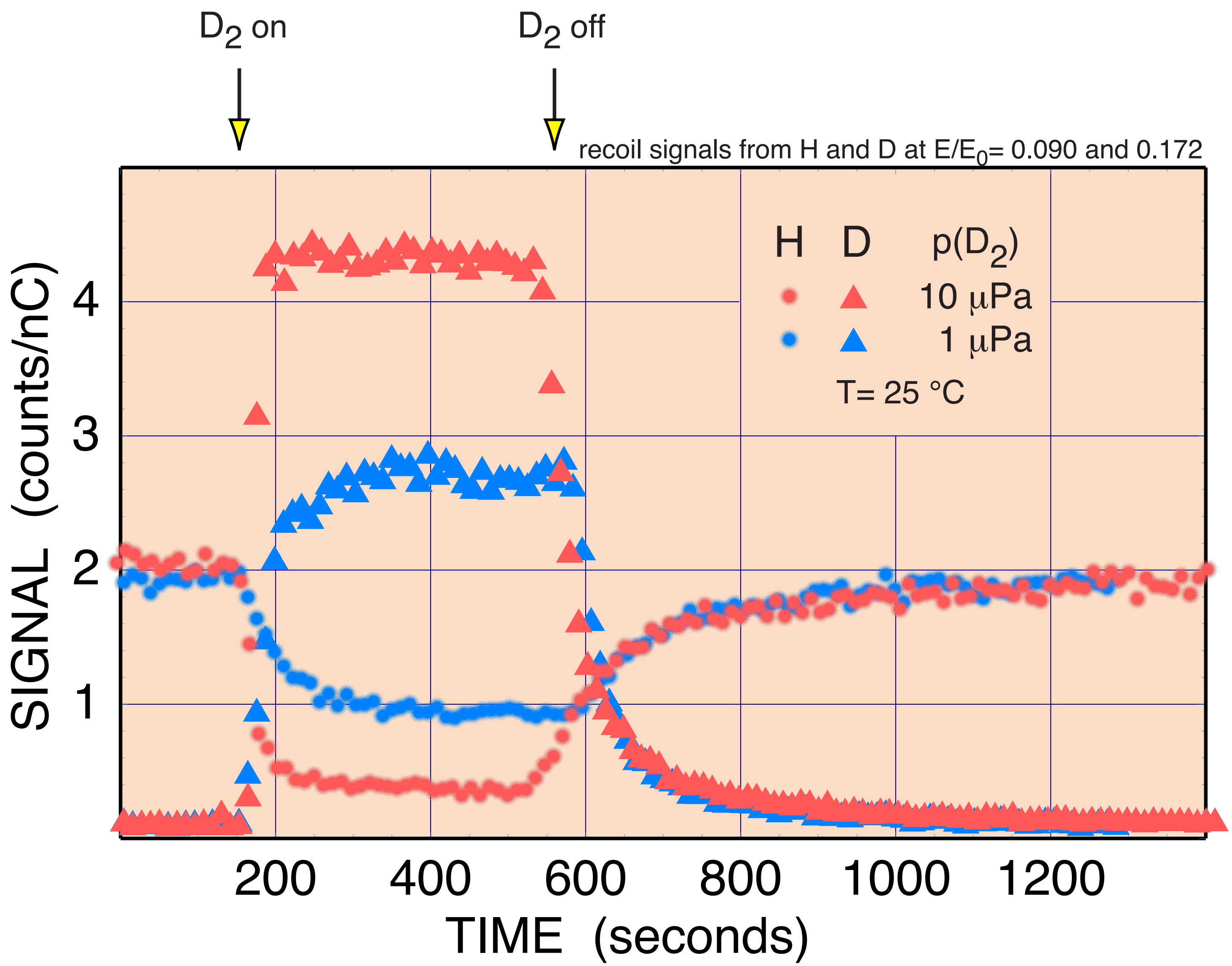
DRS detects trace levels of adsorbates.



H(ads) and D(ads) are clearly distinguished.

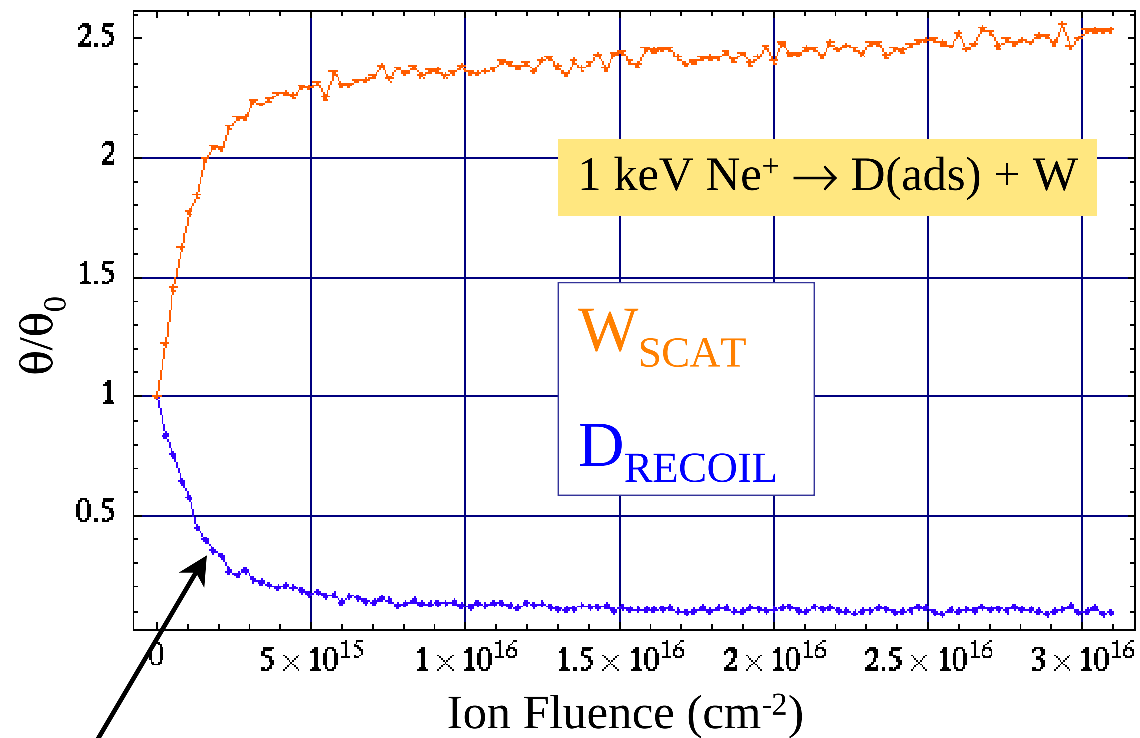


H isotopes rapidly exchange on W surfaces.



Desorption of D(ads) on W
monitored by D recoil and W scattering signals

- Data recorded from the time that the D_2 feed to the chamber was cut off
- Background (zero coverage) signal present

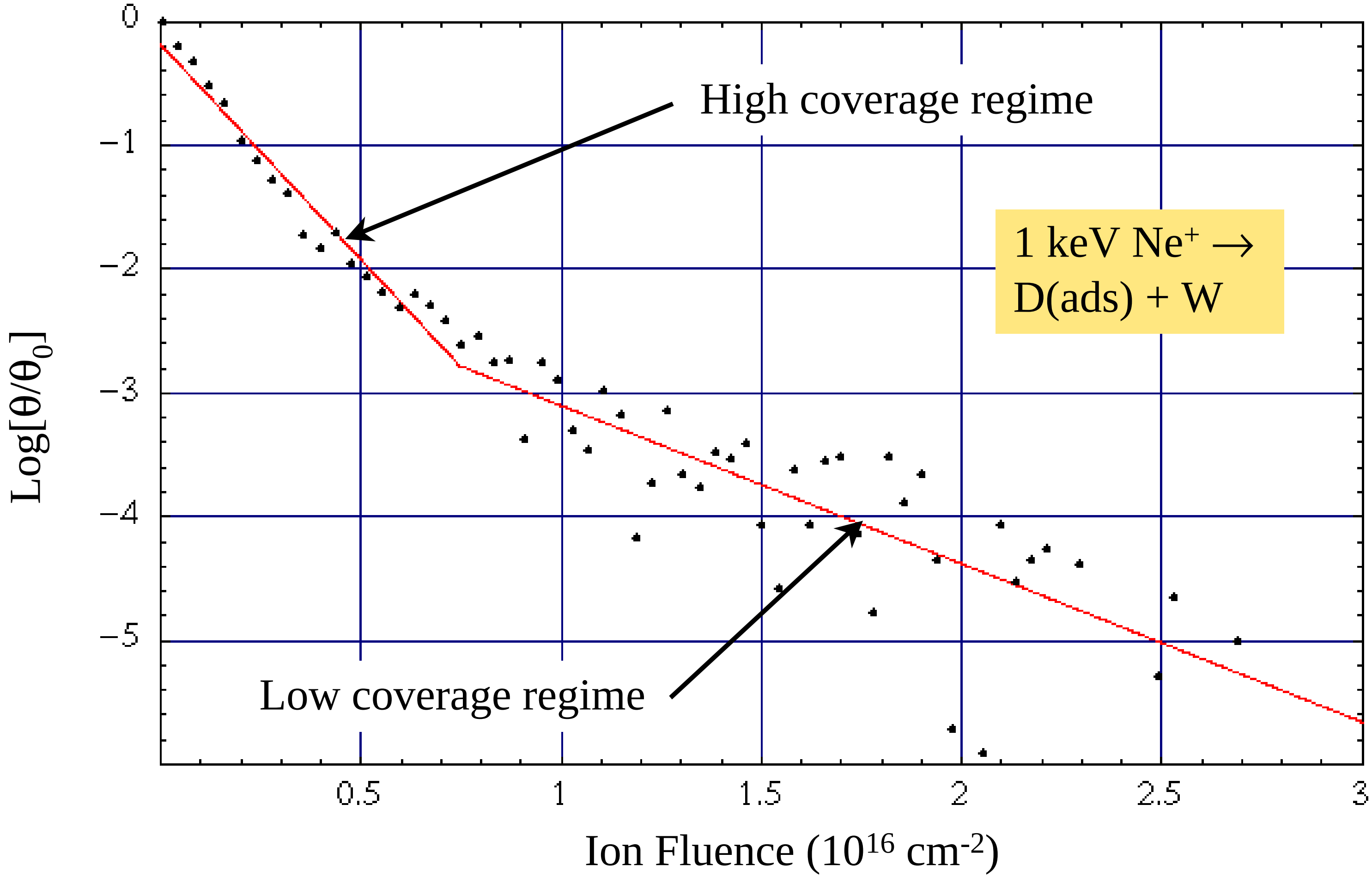


Signal of Interest

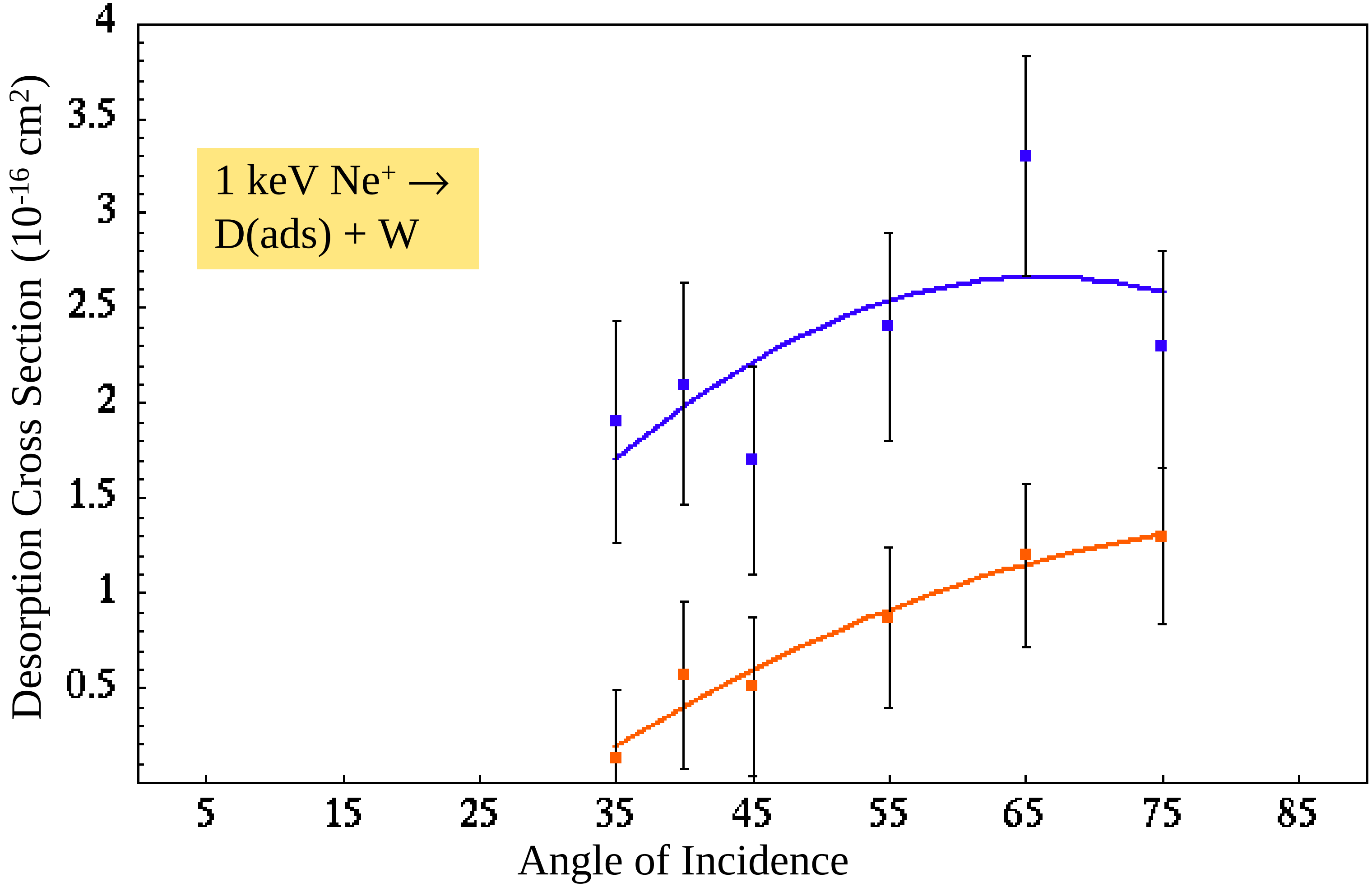
1 keV $Ne^+ \rightarrow W + D$ (ads)

$\alpha = 65°$ $\theta = 60°$

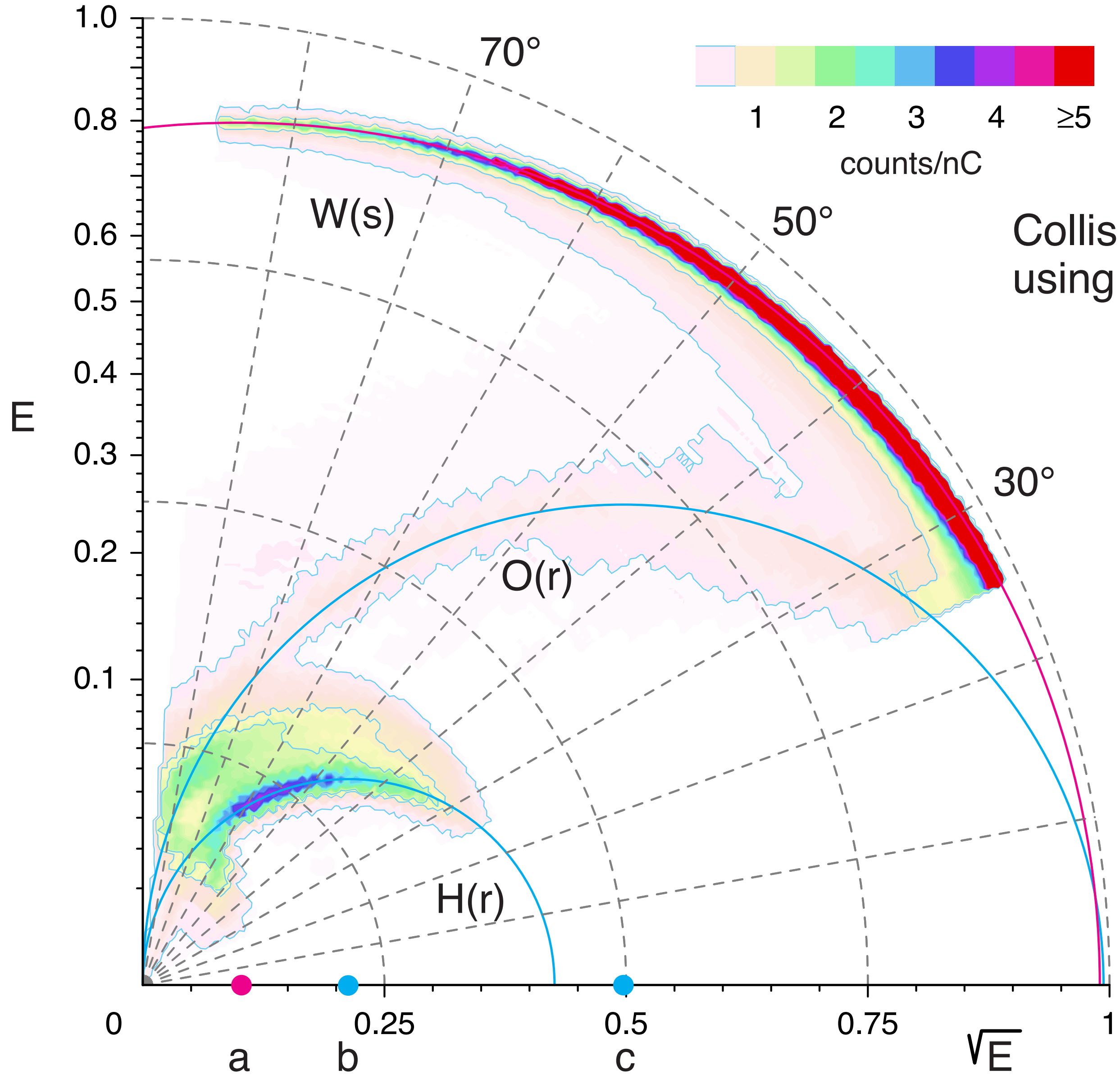
Log[Relative Coverage] vs. Fluence Plot
Exponential decay constant indicates cross section



Angular Dependence of σ_{des}



Energy-angle plot for a sputtered W surface



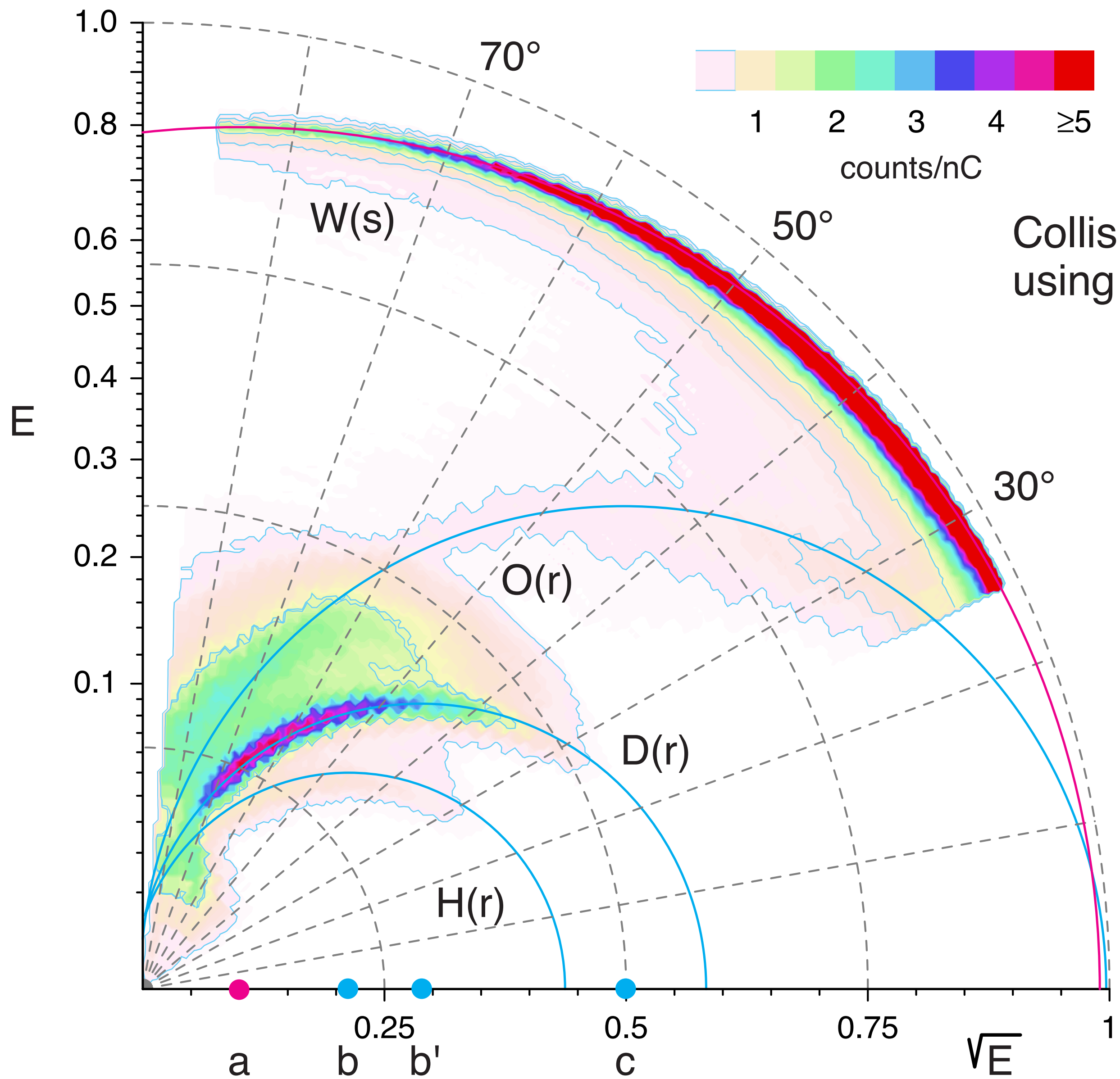
3 keV $Ne^+ \rightarrow$ W

Collision events are identified using scattering & recoil circles.

Note: scattering circles pass near the point (1,0°) and recoil circles intersect the origin.

center	x	atom
a	0.10	W
b	0.21	H
c	0.50	O

Energy-angle plot for a W surface exposed to D_2



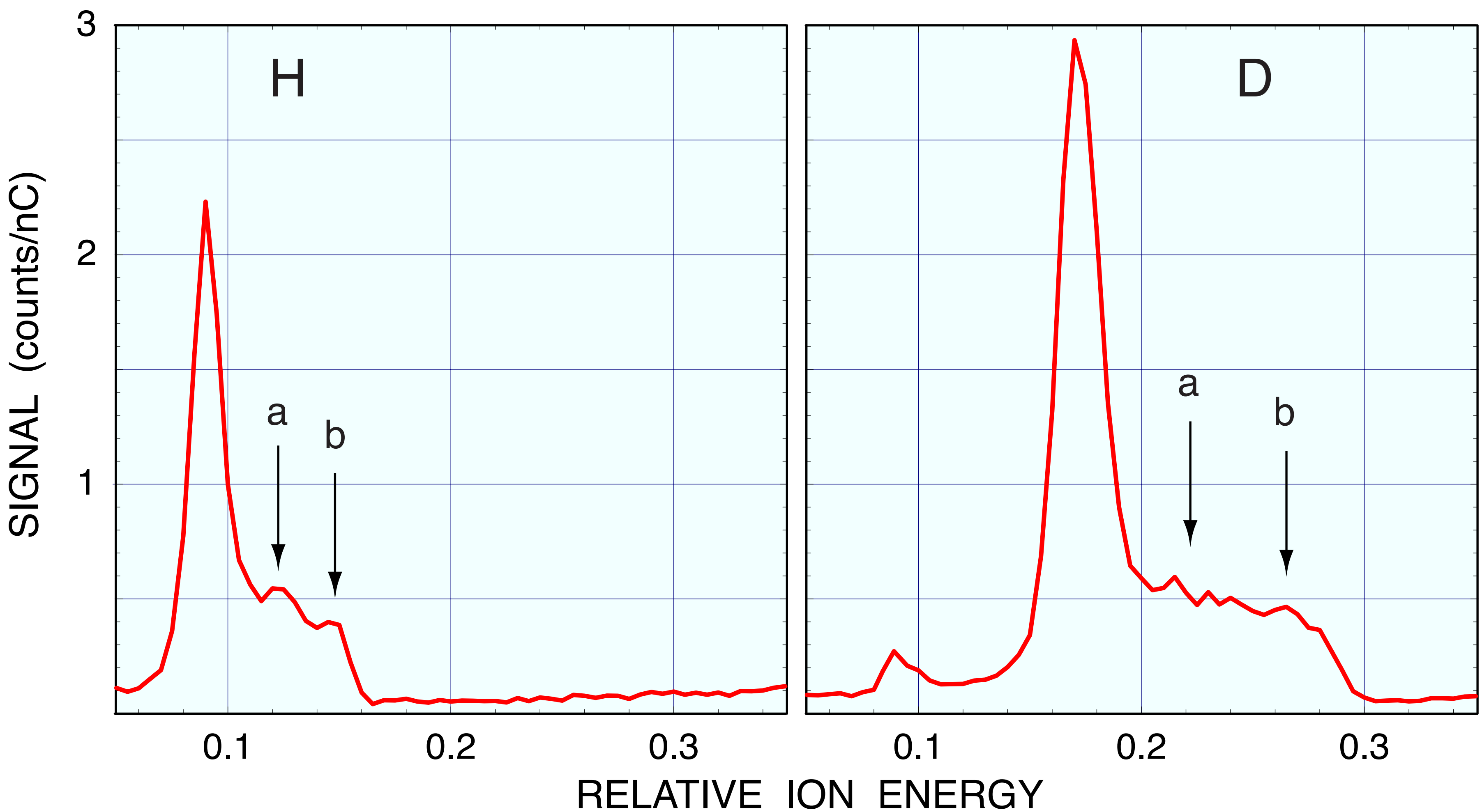
3 keV $Ne^+ \rightarrow$ W

Collision events are identified using scattering & recoil circles.

Note: scattering circles pass near the point (1,0°) and recoil circles intersect the origin.

center	x	atom
a	0.10	W
b	0.21	H
b′	0.29	D
c	0.50	O

H and D recoils show high-energy structure.



3 keV $Ne^+ \rightarrow$ H or D adsorbed on W

A kinematic analysis indicates the structure is due to recoil followed by scattering.

The initial recoil angle, θ_r, was calculated from the observed peak positions using the relation:

$$\theta_r = \arccos\left(\frac{1+A}{2}\sqrt{\frac{E_r}{A}}\right).$$

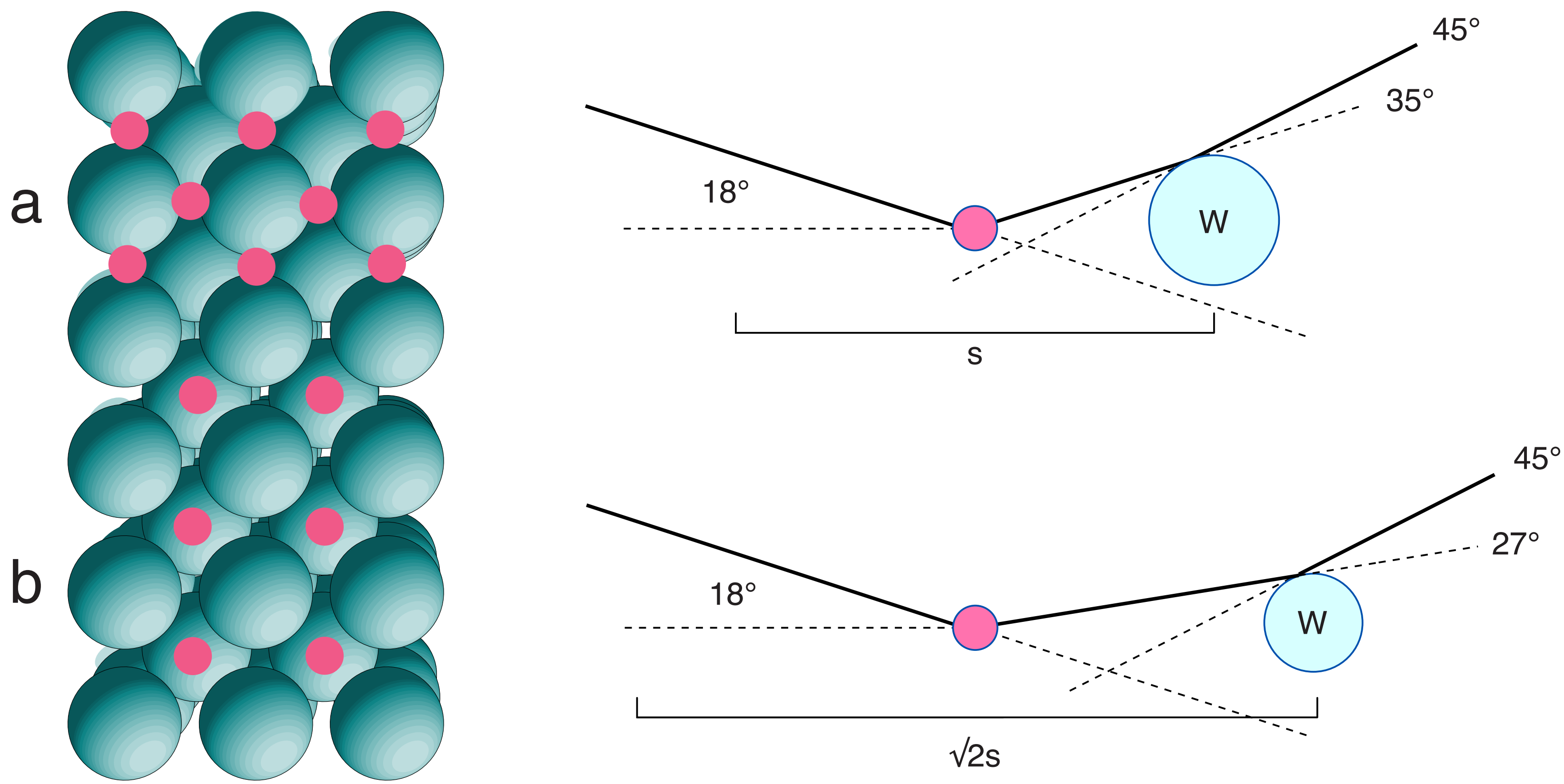
The peak positions and inferred recoil angles are listed in the table.

H$^+$ and D$^+$ energies and recoil angles   3 keV Ne$^+$ $\rightarrow$ W

E/E_0 at $\theta = 45^\circ$			
peak	H	D	θ_r
main	0.091	0.17	45°
a	0.12	0.22	35°
b	0.15	0.26	27°

Note: It is not necessary to include an energy loss term for subsequent scatteringof the recoil particle by a W atom since the large mass ratio gives $E_S \approx 1$ at small scattering angles.

Analysis of the collision geometry indicates adsorbed H isotopes are bound at bridge and hollow sites on the W surface.

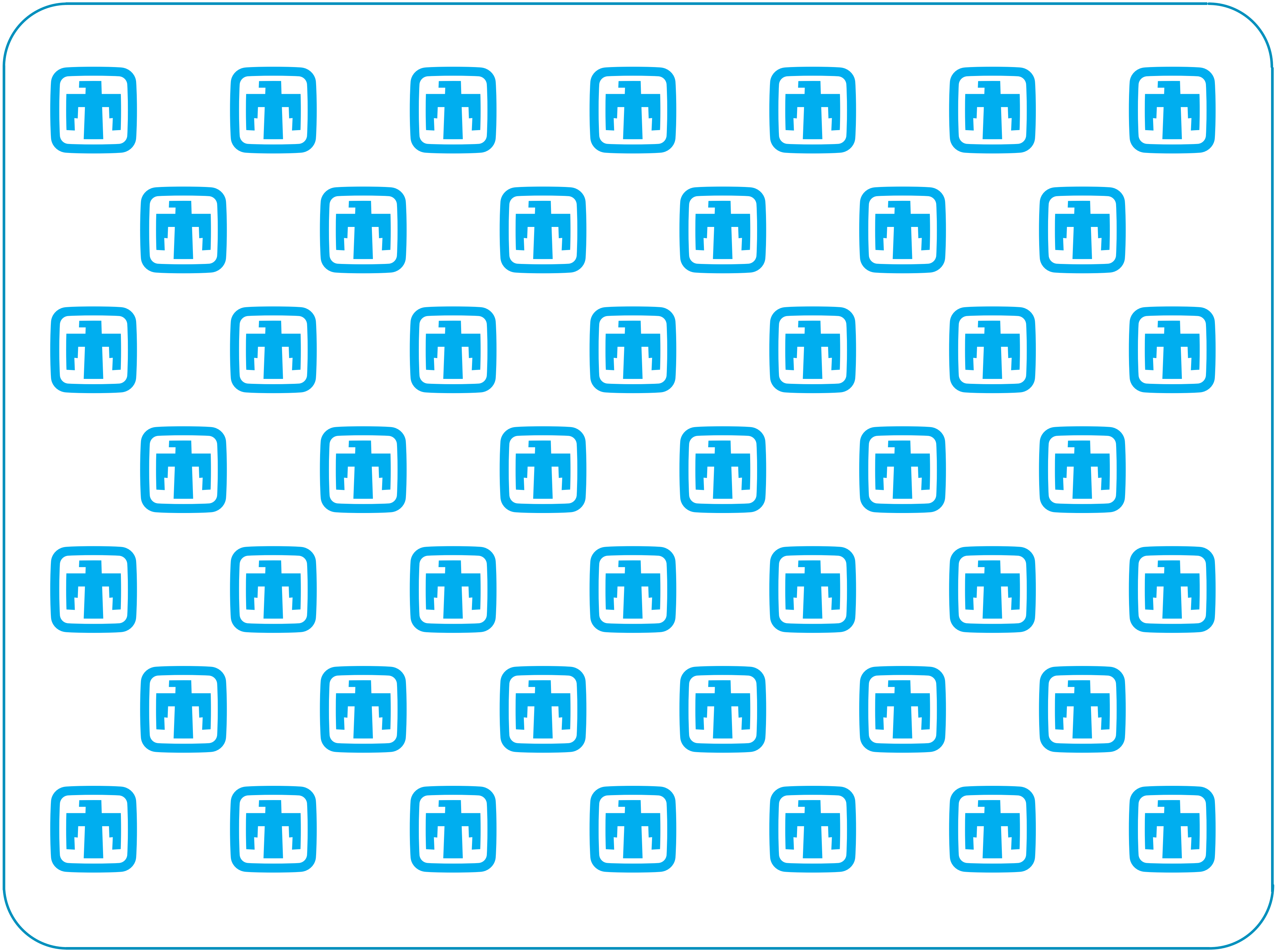


Conclusions (1)

- H isotopes readily adsorb on sputtered W surfaces.
- H isotope exchange is rapid.
- There are at least two types of binding sites on the surface.
- H isotopes bound at high-coverage sites desorb about $3\times$ more efficiently than those bound in low-coverage sites.
- Ion impact desorption cross sections for 1 keV Ne^+ range from 0.1 to 3×10^{-16} cm^2.
- The cross section increases at oblique angles of impact

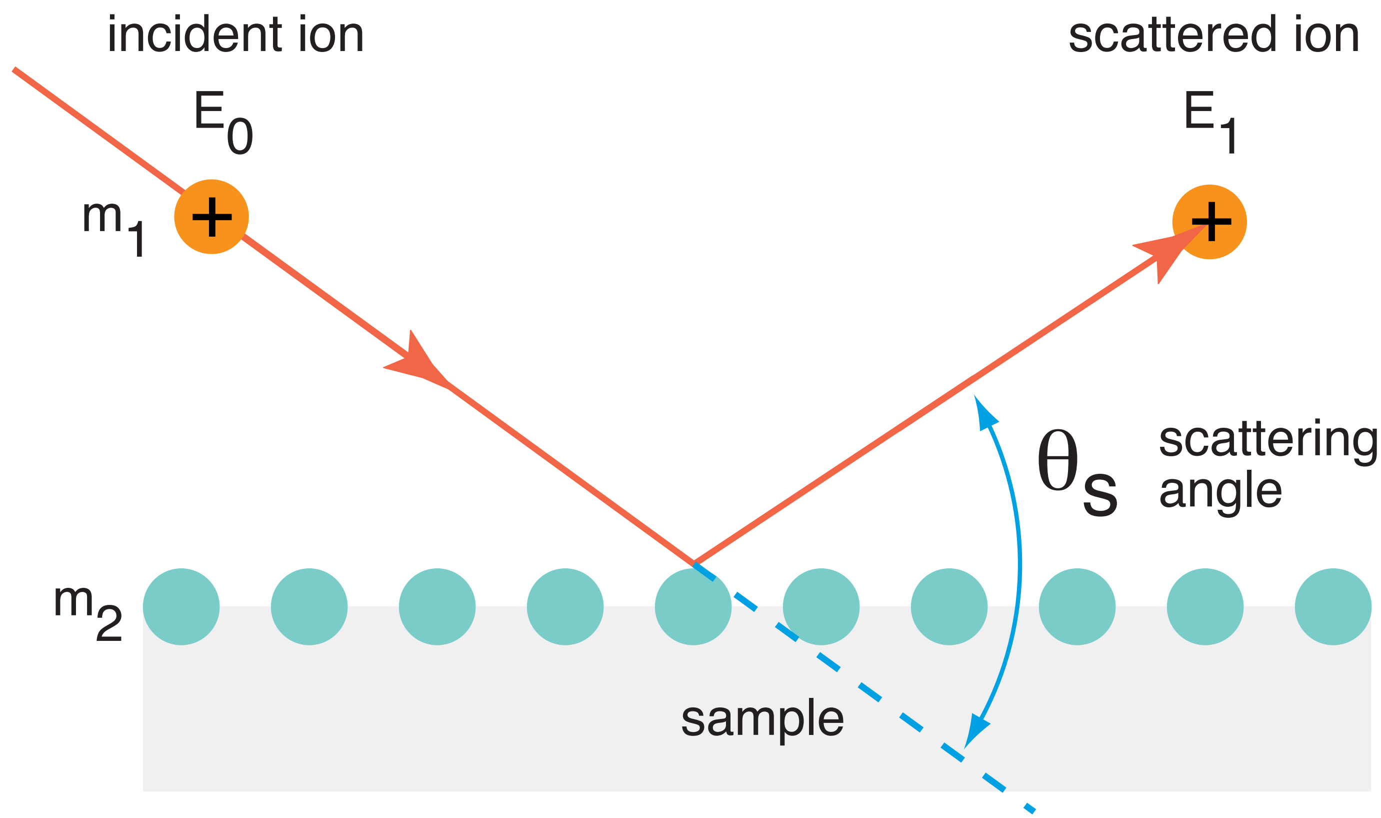
Conclusions (2)

- H isotopes recoiled from W surfaces have an energy distribution with structure that extends above the elastic recoil energy.
- The high-energy structure results from multiple collisions: recoil at a shallow angle followed by scattering from an adjacent W atom.
- Peaks in the high-energy structure are attributed to recoil of H isotopes adsorbed in bridge and hollow sites on the W surface.
- This effect will tend to enhance recycling from plasma-facing W surfaces and reduce energy transfer to the W substrate.
- Modeling of PSI on W components may need to take this effect into account.



LEIS spectroscopy consists of measuring the energy of ions reflected from a surface.

LEIS: low – energy ion scattering

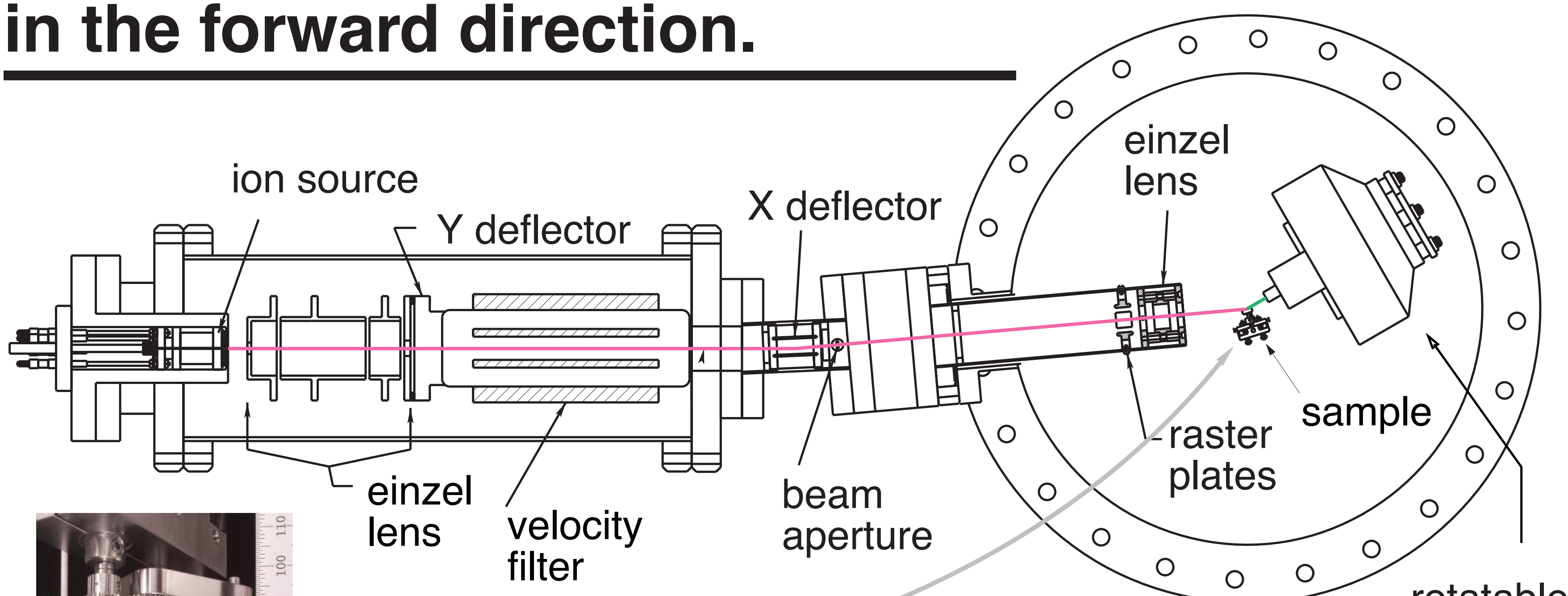


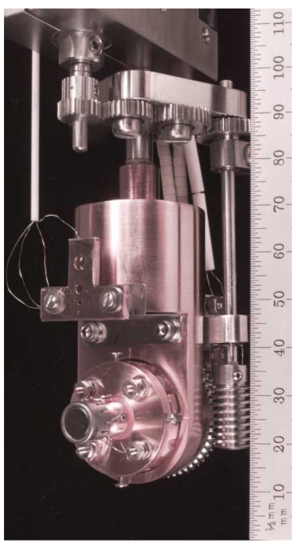
$$E_s = \frac{E_1}{E_0}$$

$$2\cos\theta_s = (1 + A)\sqrt{E_s} + (1 - A)/\sqrt{E_s}$$

(for elastic scattering)

The DRS/LEIS instrument ARIES measures the energy of ions scattered or recoiled in the forward direction.





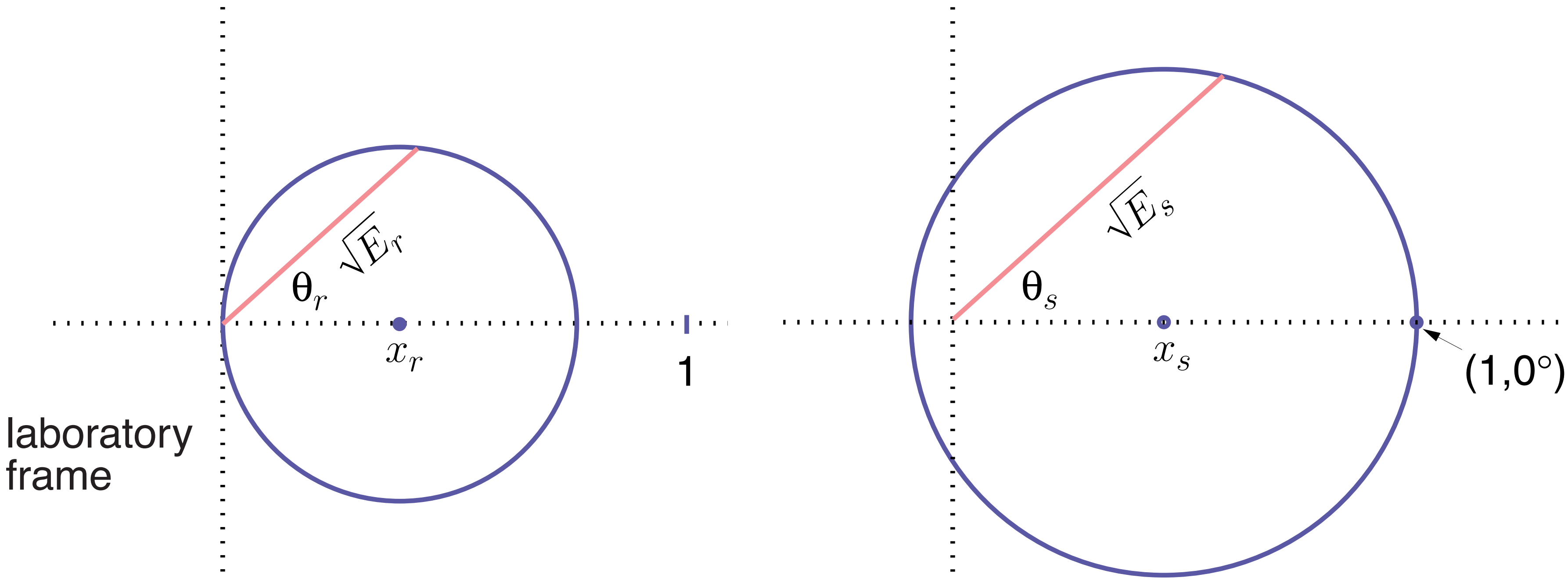
5-axis manipulator
with heating, cooling,
and remote sample
handling

ARIES:

angle-resolved
ion energy spectrometer

The recoil and scattering kinematic relations are circles in polar coordinates.

$$2\cos\theta_r = (1+A)\sqrt{E_r/A} \qquad 2\cos\theta_s = (1+A)\sqrt{E_s} + (1-A)/\sqrt{E_s}$$



center at $\sqrt{A}/(1+A)$ center at $1/(1+A)$

$$A = m_2/m_1 \qquad E_r = E_2/E_0 \qquad E_s = E_1/E_0$$